ARMY RESEARCH LABORATORY

Technical Note on Scale Conversion for the Synchronous Impulse Reconstruction (SIRE) Radar

by Kenneth Ranney, Lam Nguyen, and Anders Sullivan

ARL-TN-0286   **July 2007**

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14. ABSTRACT

This technical note describes a calibration method used to convert measurements obtained with the U.S. Army Research Laboratory synchronous impulse reconstruction (SIRE) radar from an integer scale to an absolute, radar cross section (RCS) scale. The required RCS reference point is obtained from highly accurate solutions of Maxwell's equations for a modeled reference target and scene. Electrical characteristics of this modeled target and scene are carefully selected to match those encountered in the actual data collection.

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Introduction

A well-understood, absolute measurement scale plays a critical role in understanding the physical phenomena observed in radar data. Such a scale provides a common reference frame and enables comparison of synthetic aperture radar (SAR) data collected from multiple radar sensors. For this reason, the Synchronous Impulse Reconstruction (SIRE) radar team wishes to determine a scale factor that allows measurements expressed in a scale based on analog-to-digital (A/D) counts to be converted to radar cross section (RCS) values.

In many applications, a particular reference target of known RCS, typically a point-like target, is placed in-scene to provide a calibration reference signal. The RCS of this reference target has been determined theoretically and, therefore, provides a reference number for scaling the corresponding target response observed in SAR imagery. If, however, a theoretical number is not available for a particular reference target, then a different approach is required. The extremely low depression angles inherent in the SIRE radar operation make the classical theory-based approach impractical. Thus, we have implemented a unique mixture of high fidelity electromagnetic (EM) modeling results and data measurements to obtain the desired calibration scale factor. This technical note briefly describes the approach that we have adopted.

Technical Approach

As mentioned above, we have used results from high fidelity electromagnetic models and EM-solvers in conjunction with measured radar data to obtain a calibration factor for the SIRE radar. This factor maps image pixels within the focused SAR image from their original values into commonly used RCS values.

In order to obtain the necessary RCS reference point, we select a canonical target deployment and model both the target and the SIRE radar system (i.e., frequency band and operational geometry). Using high fidelity EM-solvers developed at ARL, we then solve for the RCS of the canonical target at many individual frequencies within the frequency band of interest. Since the solvers yield both a magnitude and phase at each frequency, we are able to filter the outputs as desired. That is, we can invoke Parseval's theorem to relate the energy reflected by the canonical target in both the modeled and measured cases.

As part of this approach we make the following approximations that allow us to relate radar measurements to results obtained using the EM-solvers:

a. The time domain response of the sphere approximates a point target. Hence, the peak value from the sphere captures almost all of the energy along that particular down-range cut.

b. The focusing procedure is linear and provides adequate cross-range resolution to isolate the canonical target from any neighboring background clutter.

c. Due to symmetry, the measured sphere RCS will not be affected by integration in the direction that the vehicle travels (i.e., along-track integration).

Pareseval's theorem states that:

$$\sum_{n=0}^{N-1}|f(n)|^2 = \frac{1}{N}\sum_{m=1}^{N-1}|F(m)|^2 ,\qquad(1)$$

where $f(n)$ is the time-domain sequence and $F(m)$ is its discrete Fourier Transform. Since we approximate the sphere by a point target, we select a particular down-range cut in the focused SIRE image data and use it in the left-hand side of (1), replacing $\sum_{n=0}^{N-1}|f(n)|^2$ in (1) with $\max_n\{|f(n)|^2\}$. We then substitute the appropriate frequency domain data from the EM-solvers in the right-hand side of (1). After these substitutions, the two sides of (1) will differ by some scale factor, and this scale factor becomes our calibration correction. That is,

$$\alpha = \frac{\frac{1}{N}\sum_{m=1}^{N-1}|F_{modeled}(m)|^2}{\max\{|f_{measured}(n)|^2\}} ,\qquad(2)$$

where N represents the number of frequency samples used (as determined by the bandwidth used to form the focused image).

After application of the scale factor, we are left with the approximation

$$\alpha\sum_{n=0}^{N-1}|f_{measured}(n)|^2 \approx \frac{1}{N}\sum_{m=1}^{N-1}|F_{modeled}(m)|^2 ,\qquad(3)$$

which represents the result in the converted scale obtained by forcing the Parseval relationship to hold.

We note here that the scale factor, α, obtained in this way may change as the bandwidth used to obtain the focused imagery changes. Thus, we will calculate a new scale conversion factor for each bandwidth of interest based on modeled and measured data.

The appendix includes examples of focused SIRE imagery together with the calibration factor calculated for each case.

Summary

This technical note described a method for converting radar measurements from a scale based on A/D output values to a universal scale based on RCS. The desired conversion factor is obtained by invoking Parseval's Theorem together with a few simplifying assumptions. For this reason, it is valid only for the bandwidth used to obtain a particular focused image. It can easily be applied to any image of interest, however, provided that both modeled and measured data exist. It is the incorporation of outputs from high fidelity EM-solvers that differentiate the proposed method from many methods commonly used in practice.

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Appendix. Examples of Calibration Factors Calculated for Various SIRE Images
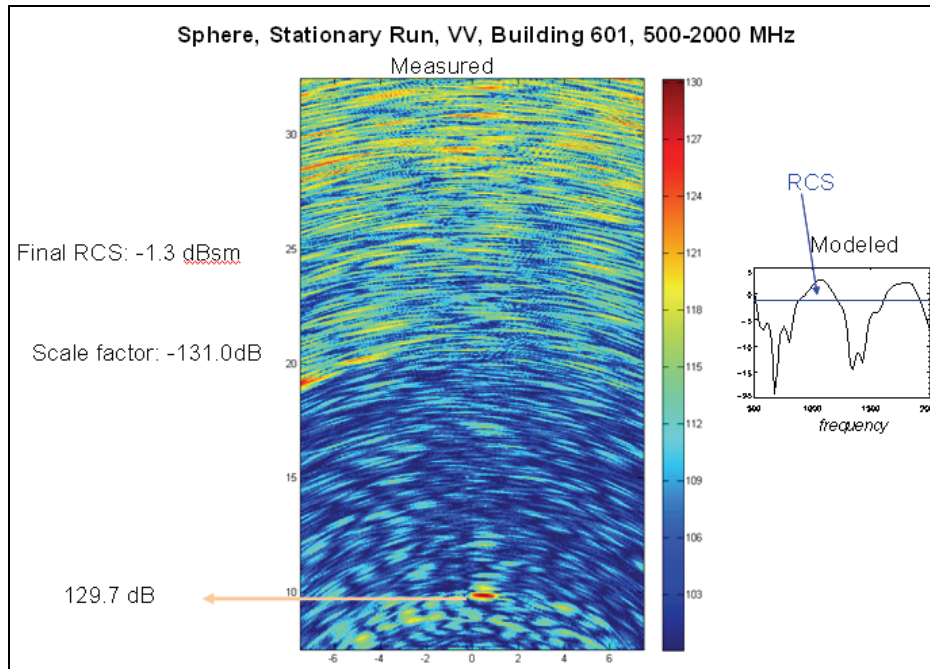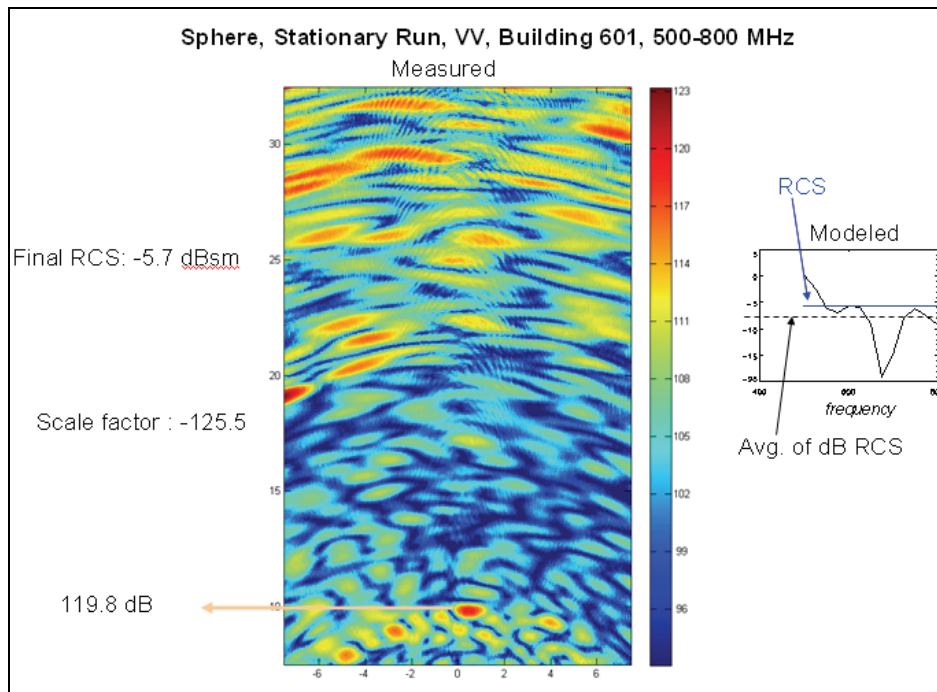

Figure A-1. Image bandwidth 500–2000 MHz.

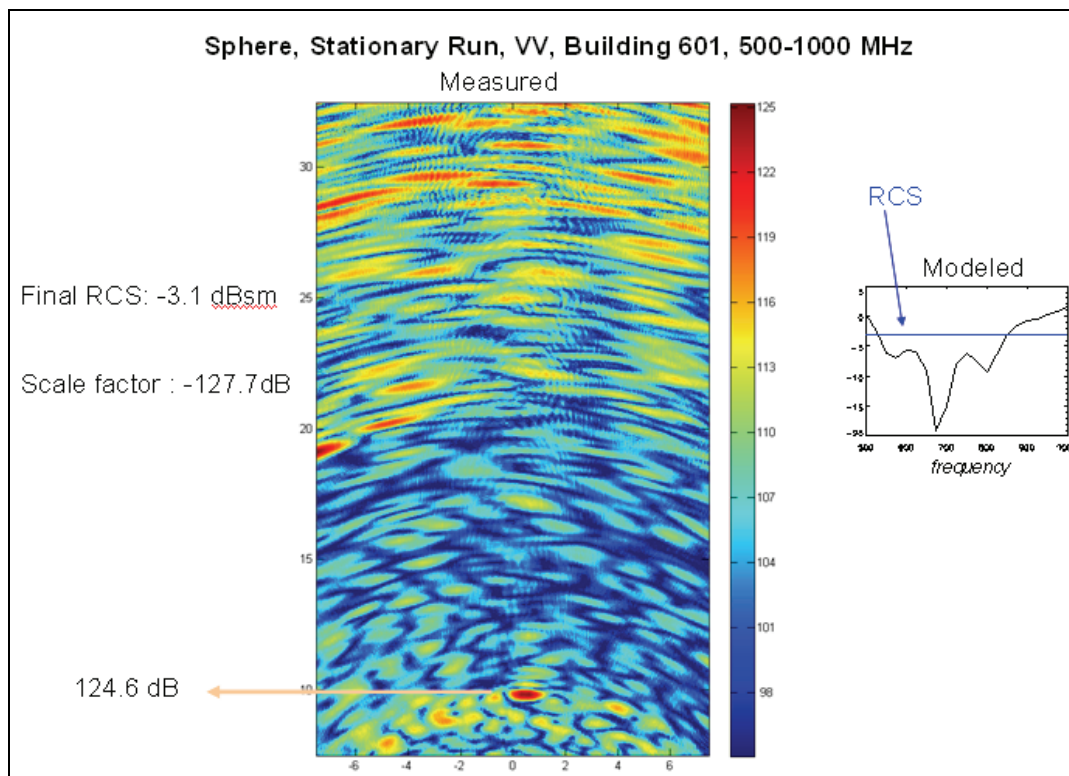Figure A-2. Image bandwidth 500–800 MHz.
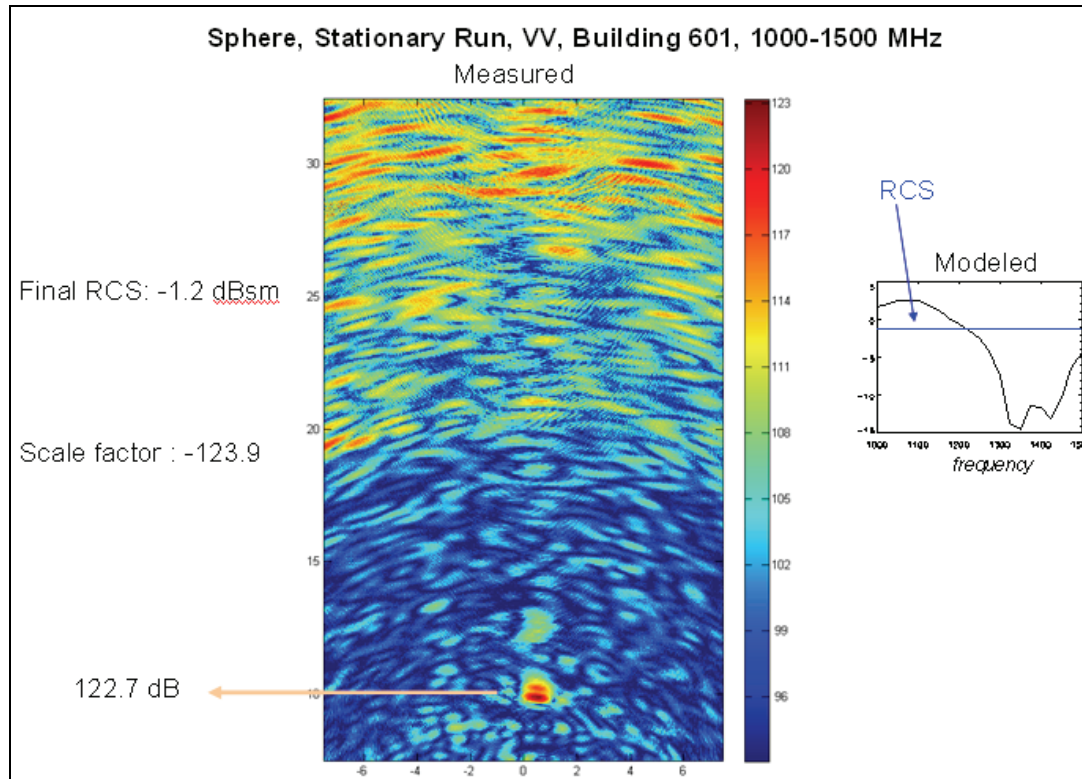
Figure A-3. Image bandwidth 500–1000 MHz.
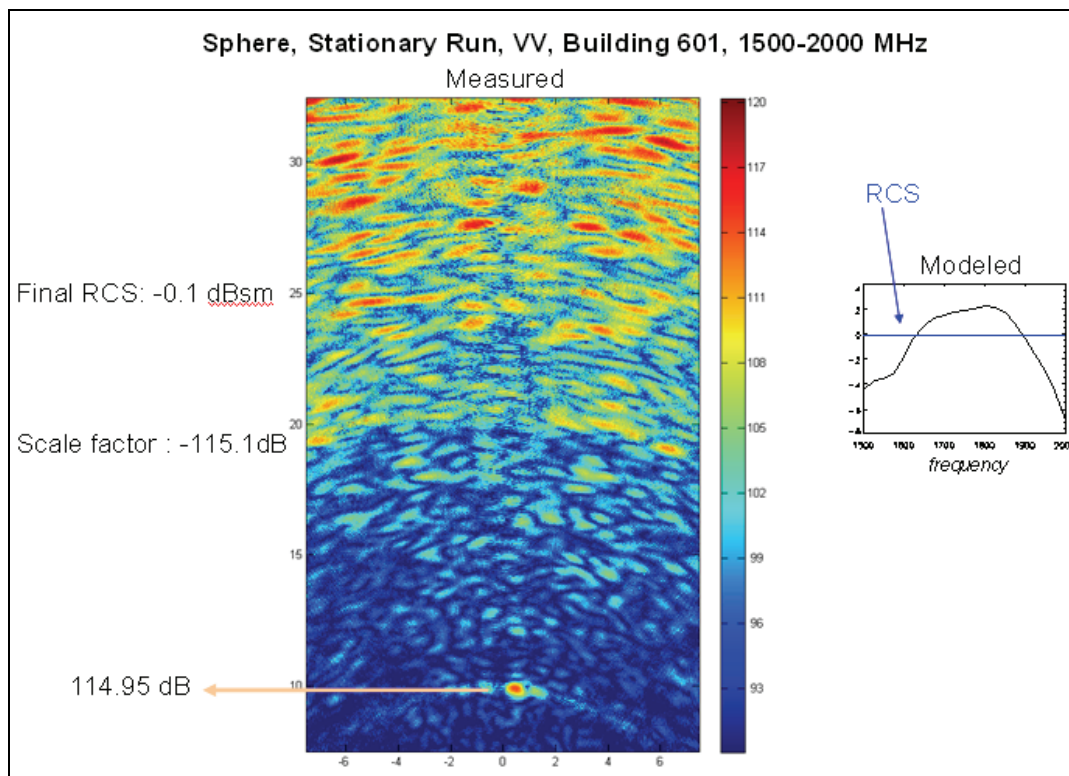

Figure A-4. Image bandwidth 1000–2000 MHz.

Figure A-5. Image bandwidth 1500–2000 MHz.

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